

Improving the Rheological and Mechanical Properties of Oil Well Cement Slurries Using Multiple Chemical Admixtures for Enhancing Zonal Isolation: A Laboratory Evaluation

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ABSTRACT

The study uses chemical and mineral admixtures to understand the critical processes affecting the cement slurry characteristics, including rheological properties, free water, compressive strength, and thickening time. Using alternate mineral admixtures to replace cement slurry partially has environmental and economic benefits. The mechanisms behind the effects of chemical admixtures on the parameters of cement slurry were investigated at different temperatures using cutting-edge experimental equipment. The binder's compatibility and reactions with chemical admixtures were examined. When temperature and chemical admixtures are combined, it has a major effect on the flow characteristics of slurries. The results suggested that present technical data for chemical admixtures must be confirmed for use in oil well cementing; admixtures that are efficient at raised temperatures in conventional cementing work may become ineffective at elevated temperatures in oil well cementing. Finally, the new mixture can be employed in the desired oil field due to this new material generation (4,200-6,900 feet and pressure and temperature range of 4,100-4,800psi and 140-170°F, respectively). Because this mixture enhances the rheological properties of cement slurry, the end product will be better than the current version. After all, the plastic viscosity, apparent viscosity, and yield stress diagrams of mixture #3-A are lower than the desired oil field. The other mixtures in this study lead to a decrease in cement slurry viscosity and have the highest compressive strength. Finally, mixture #3*-A was the optimal blend.*

Keywords: Rheology, Admixture, Compressive Strength, Thickening Time, Compatibility.

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1. INTRODUCTION

Petroleum exploration and production significantly impact the world's economic structure [1, 2]. The global oil demand has been rising steadily during the last few years. Between 1965 and 2008, it increased by 171 percent [4, 10, 28]. Throughout the previous two decades, the estimate of recently found oil reserves has been exceeded by the annual assessment of oil consumption [12, 15, and 29]. As a result, the possibility of a significant drop in oil production is increasing with time. Regardless, the accuracy with which unfamiliar oil stores are measured is not exceptional [9, 14, and 21]. Therefore, it is challenging to predict when a definitive drop in oil output will begin and how it will impact the global economy. Human society, particularly the current innovative society, depends on the global supply of oil and chemical materials. [7, 18, and 25]. Oil spills generate ecological disasters due to harmful substances other than financial catastrophes, particularly in marine areas. The oil industry has invested billions of dollars in developing mechanically driven equipment and supplies to enhance oil extraction and reduce oil and gas loss [3, 26]. In any case, the reality is that it is difficult to address each new issue that arises. In oil, gas, and water wells, constructing a well entails injecting solid slurry into the annular space between the well packing and the wellbore geological formations to provide zonal separation [13, 16, and 24]. The goal is to keep fluid liquids like water and gas from moving between different well areas. Blemished zonal segregation and a sensitive pressure-driven barrier between the packing and the solid and between the cement and the developments could result in oil slicks. The well may never operate at full capacity. The rheological properties of oil well concrete (OWC) slurries must be upgraded to achieve a productive, well-established methodology [5, 11, and 23]. In the recent few decades, a variety of new synthetic material admixtures, such as plasticizers, retarders, and thickness modifying admixtures, have been disclosed to improve the development properties of bond-based items. At an early stage, cement-organized frameworks' age and hardened properties rely on the sort and pharmaceutical measurement of concoction substance admixtures utilized. The correct collection of concoction ingredient admixtures is based on learning from your mistakes and, for the most part, on laboratory tests. Admixtures of compound substances are carried out under the auspices of the synthetic material and the solid's physical qualities. Numerous commercial compound

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admixtures have been successfully used in Ordinary Portland Concrete. As a result, the unique information materials provided by producers are generally unsuitable for oil well solidification. As described by the American Petroleum Institute (API), a specific class of concretes known as oil well cement slurry is frequently found in the slurry piece to adjust to base gap circumstances (a wide range of weight and temperature), as described by the American Petroleum Institute (API). At increased temperatures, the relationships between cement slurry, different admixtures, and the relevant cement admixture similarities are still being researched. The rheological properties of concrete-based materials impact the evaluation of the established cementations framework and can help predict its end-use execution and physical characteristics after and during preparation [8, 17, and 20]. Determining the rheological characteristics of bond-based materials in the lab is still a test approach. The water-to-bond proportion (w/c), the size and state of the bond shape and size of bond grains, the synthetic structure of the solid, and the similar syndication of its segments at the highest point of grains, the type and event of added substances, the similarity of concrete and concoction substance admixtures, the similarity of compound substance and solid admixtures, testing and characterization are all factors that influence the rheological properties of a solid. Additionally, sliding at the slurry-shearing surface UI amid rheological appraisals, molecule collaborations, concoction substance responses, nonhomogeneous stream fields, and individual human issues can make the rheological tests hard to imitate [6, 19, and 22]. Most importantly, while the equipment used to measure the rheological of concrete-based materials properly is relatively inexpensive, the rigging used to evaluate the rheological of bond-based materials is generally prohibitively expensive, difficult to operate, and may not be precisely suited for use in newly developed areas due to its large size and muddled setup [4, 27, 30]. The paper examines the effect of typical chemical admixtures on the rheological characteristics of oil well cement slurries in depth. This research helps produce guidelines and requirements for using these admixtures in oil well cementing. Similarly, this study examined the effects of common chemical admixtures generated in countries with mild temperatures on occupations requiring cement above ground. The study's findings show that not all admixtures studied are suited for oil well-cementing work due to their potential for producing disappointing outcomes when exposed to elevated temperatures. Thus, the findings of this study

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indicate that technical specifications for chemical admixtures used in oil well cementing should be revised to account for the harsh down-hole environment.

2. MATERIALS AND METHODS

2.1. SELECTIVE ADDITIVE

2.1.1. MATERIALS

The cement slurries used in this experiment had a specific gravity of 3.14 and were prepared with API Class G oil well cement with a high sulfate resistance. The chemical and physical properties of this cement are listed in Table 1. Water was utilized to mix, and its temperature was kept at ambient. Six major chemical admixtures, three dispersants, three retarders, and three subsidiary chemical admixtures were used in three different cement slurries mixtures, and their effects on the rheological characteristics and other properties of cement at different temperatures and dosages were evaluated. The following are all of these admixtures:

1. A new generation of calcium lignosulfonate (CLS) dispersion was utilized in the cement slurry at specified concentrations of 1.066 percent, 1.2 percent, and 1.33 percent by weight of cement as a dispersant.
2. Boric acid (BA) was utilized in this investigation as a retarder in the cement slurry to meet the ASTM C494 standards at specified concentrations of 0.4 percent, 0.533 percent, and 0.67 percent by weight of cement.
3. Dextrose (Dex) was utilized as a dispersant in this investigation at three different concentrations, namely 1.066 percent, 1.2 percent, and 1.33 percent by weight of cement.
4. This study used citric acid (CA) as a retarder in cement slurry that met ASTM C494 standards at specified concentrations of 0.4 percent, 0.533 percent, and 0.67 percent by weight of cement.
5. Using D-1 as a dispersant with ASTM C494 standards at three dosages of 0.53 percent, 0.6 percent, and 0.67 percent by weight of cement, the effect of D-1 on the rheological characteristics of slurries at field temperature was investigated.
6. R-1 retarder I cement slurry matching ASTM C494 criteria was employed in this study at three dosages of 0.166 percent, 0.23 percent, and 0.3 percent by weight of cement.

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7. To avoid settling the cement slurry during mixing, 0.4 percent by weight of cement is employed as a fluid loss control D-167 (FLC) that meets the ASTM C494 standards at one dosage.
8. NaCl meets ASTM C494 criteria in a single dosage; 14.5 percent by weight of water is added to the cement to increase its compressive strength.
9. Nano silica (HSL) is added to the cement slurry at three concentrations: 0.133 percent, 0.126 percent, and 0.4 percent by weight of cement. This chemical is purely to determine the correct dosage for various mixtures.

2.1.2. MIXTURES

The qualities of three distinct combinations, or three new generations of retarders and dispersants, will be investigated. The following tables detail the composition of mixtures.

2.1.2.1. COMPOSITION OF MIXTURE #1

This mixture contains dispersants and retarders made from calcium lignosulfonate (CLS) and boric acid (BA). Additionally, fluid loss control D-167 (FLC) prevents the cement slurry from settling. The ingredients of mixture #1 are listed in the following table (Table 2).

2.1.2.2. COMPOSITION OF MIXTURE #2

This mixture contains dextrose (Dex), citric acid (CA) dispersants, and retarders. Additionally, fluid loss control D-167 prevents the cement slurry from settling. The ingredients of mixture #2 are listed in the following table (Table 3).

2.1.2.3. COMPOSITION OF MIXTURE #3

The dispersants D-1 and R-1 are used as retarders, and salt (NaCl) is added to the mixture to enhance the compressive strength of the cement slurry. The following table lists the components of mixture #3. (Table 4).

2.1.2.4. COMPOSITION OF MIXTURE #3*

This is the identical composition to mixture #3. On the other hand, Nano-silica is added to this combination to enhance the cement slurry's rheological properties and compressive strength. Additionally, just one concentration of mixture #3 is considered (the worst-case scenario regarding rheological qualities), adding Nano-silica. The ingredients of mixture #3* are listed in Table 5.

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2.2. CEMENT SLURRY PREPARATION

A high-shear blender-type mixer (Figure 1) with bottom-driven blades was used to make the cement slurries. After that, the blender was filled with mixing water. The needed amount of liquid additive was then added to the mixing water with a needle. The water was mixed slowly (4,000 rotations per minute), and then solid chemical admixtures were added. To guarantee that chemical admixtures are completely dispersed in the water, wait 1 minute after adding any ingredient. The cement was added to the liquids over 15 seconds (liquid admixture and water). Manual mixing was performed for 15 seconds to ensure homogeneity, and material sticking to the mixing container's wall was recovered with a rubber spatula. Finally, for another 35 seconds, mixing was resumed at high speed (12,000 rpm). This mixing technique was properly followed for all cement slurries. All mixing was done in a room with a constant temperature of 25°C.

2.3. DENSITY DETERMINATION OF CEMENT SLURRY

The test is to fill the cup with mud or cement and identify the proper rider position for balance. Water is frequently used as the calibration fluid. The density of freshwater is 8.33 lb/gal.

2.4 DETERMINATION OF THE RHEOLOGICAL CHARACTERISTICS OF CEMENT SLURRY

2.4.1 CONSISTOMETER FOR CEMENT

After creating the slurry in the mixer, the density was calculated. The slurry was transferred to the bowl of the consistometer (Figure 2) for 20 minutes at the test temperature (140°F, 160°F, 170°F) at a speed of 150 rpm. To eliminate the effect of exogenous variables on the outcomes, the total time between mixing and the rheological testing was kept constant. Moreover, the rheometer setup was maintained consistently for all slurries. The concentric cylinder test configuration was maintained at the test temperature to avoid the slurry facing an abrupt thermal shock.

2.4.2. FANN VISCOMETER

After the cement slurry achieved the desired temperature in the consistometer, it was put into the viscometer's container. Immerse the coaxial cylinders (the instrument comprises a slide bar and a threaded clamp) in the cement until the reference mark on the rotor is flush with the surface. The rotor is spun at 600 revolutions per minute (using a velocity selection and a switch), and the scale deflection is read. The rotation speed is reset to 300 rpm without stopping

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the rotor, and the scale deflection is read again. This operation is repeated with a variety of different rotational speeds.

2.4.2.1. METHOD FOR DETERMINING APPARENT VISCOSITY

The apparent viscosity of cement slurries is determined according to API standards at a shear rate of $1,021.8 \text{ (s}^{-1}\text{)}$, which corresponds to a rotor speed of 600 revolutions per minute on a Fann viscometer. Frequently, these requirements are not defined explicitly but are denoted by "apparent viscosity."

2.4.2.2. PLASTIC VISCOSITY AND THE YIELD POINT DETERMINATION

API RP 13 B requires a Fann viscometer for these measurements. It is necessary to determine the shear stress of 510.9 at a shear rate of $2 = 510.9$ (at 300 rpm) and the shear stress of 170.3 at a shear rate of $1 = 170.3 \text{ s}^{-1}$ (at 100 rpm).

2.4.2.3. THIXOTROPY DETERMINATION

Thixotropy can be determined by monitoring how a gel's strength changes over time. Using a two-speed Fann viscometer, API RP 13 B requires the determination of two values: the 10-second gel strength and the 10-minute gel strength. The technique mentioned below is followed. After 30 seconds of operation at 600 rpm, the pump is switched off, and the small upper knurled knob is changed to its intermediate position. The large knurled knob on top of the instrument is gradually twisted counterclockwise by hand at roughly three revolutions per minute after ten seconds. The scale's maximum deviation is shown. The initial gel strength in pounds per square foot is determined using this procedure. Allow 10 minutes for the cement to settle before repeating the process. For 10 minutes, the maximum scale deflection equals the gel strength in $\text{lb}/100\text{ft}^2$. When using a six-speed Fann viscometer, the approach is the same, except that instead of manually spinning the rotor, the 3-rpm speed is applied.

2.5. DETERMINATION OF CEMENT-FREE WATER

After layer forms at the slurry column's top when cement settles. When cement settles, the greater the free water created, the less stable the suspension. This phenomenon is observed for simple cement slurries, such as cement and water alone. The amount of clean, free water at the top of a cement column can be used to determine the slurry's stability. The less stable the cement slurry is, the more free water it contains. This is the basis for the API test, which involves

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the addition of cement slurry to a 250 ml measuring cylinder, and the level of free water at the cylinder's top is measured after two hours. If the amount of free water in the measuring cylinder is less than 3.5 ml per 250 ml, the problem of free water is minor. Cohesive forces frequently decrease in most formulations containing a fluid-loss additive, dispersion, and a retarder. This is commonly accompanied by a decrease in low-shear rheology, yield point, and gel strength.

2.6. CEMENT COMPRESSIVE STRENGTH DETERMINATION USING THE ADR 2000 COMPRESSION MACHINE

The ADR Touch range of compression machines with 2,000 kN and 3,000 kN has been created to meet dependable and consistent testing requirements. This test is conducted exclusively on the optimal dosage of specially developed cement slurries.

2.7. DETERMINATION OF THE THICKENING TIME FOR THE CEMENT SLURRY

The time needed for cement slurries to thicken was determined using a device (Figure 3) under simulated downhole pressure and temperature conditions. This test is conducted exclusively on the optimal dosage of specially developed cement slurries.

2.8. NOTES

- All formulations are evaluated in three different retarder and dispersant concentrations. The total of the retarder and dispersant concentrations is considered to be constant. The following variable is examined:
 1. Shear stress versus shear rate
 2. Plastic Viscosity
 3. Yield-related stress
 4. Apparent viscosity
 5. The gel strength of ten seconds
 6. Gel strength after ten minutes
 7. Complimentary water
 8. Compressive force
 9. Time required for thickening
- All mixes are non-Newtonian and are classified as Bingham fluids.

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- The first six parameters are studied for mixes #1 and #2. Additionally, all of the parameters listed above are explored for mixture #3.
- The trials with mixtures #1, #2, and #3 are conducted at three different concentrations and temperatures of 140°F, 160°F, and 170°F.
- Each mixture is subjected to a free water test at ambient pressure and temperature.
- After examining parameters 1–7 on combination #3, the concentration exhibiting the poorest rheological qualities is chosen, and Nano-silica is applied. Finally, the mixture's parameters No. 8 and No. 9 are studied.
- Test No. 8 is conducted on combination #3 at a temperature of 170°F, which corresponds to the desired oil well's static temperature.
- Test No.9 is conducted on combination #3 at a temperature of 140°F, which corresponds to the required oil well's circulation temperature.
- All of the cement slurries used in the weight of the experiment were 120 pounds per cubic foot (PCF), similar to the weight of the cement slurry used in the desired oil well.
- The water-cement ratio (w/c) is 42.6 percent for mixtures #1 and #2 and 43.3 percent for combination #3. It should be highlighted that w/c is regarded as constant.

3. RESULTS AND DISCUSSION

The experiments conducted in this study fall into four categories:

1. The combined effects of temperature and chemical additive concentration on the rheological properties of cement slurry
2. Experiments of free water
3. Compressive strength and thickening time are affected by the concentration of chemical admixtures.
4. Comparison of laboratory and field data

3.1. THE INFLUENCE OF TEMPERATURE AND CHEMICAL ADMIXTURE CONCENTRATIONS ON THE RHEOLOGICAL CHARACTERISTICS IN COMBINATION

3.1.1. SHEAR STRESS VS. SHEAR RATE CURVES

Shear stress vs. shear rate curves for mixtures #1, #2, and #3, including three different dispersant and retarder concentrations at three different temperatures, are shown in Figures 4–

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12. The graphs show that when the temperature rises, the slope of all shear stress vs. shear rate curves falls. The viscosity of the cement slurry decreases as the slope of the curves falls. This occurs because a liquid's molecules are stimulated and move when it heats up. Since the energy of this movement is sufficient to overcome the forces that hold the molecules together, the liquid becomes more fluid, and its viscosity reduces. Also, increasing the dispersant concentration reduces the viscosity of the cement slurry and the slope of the shear stress vs. shear rate curves, as shown in each mixture diagram. Consider the diagrams of mixtures #1 and #2; all data are positioned on a straight line that does not intersect the coordinate set's origin; as a result, the behavior of cement slurries is classified as Bingham Plastic (Non-Newtonian) fluid. The data in mixture #3 are linear and diagram more linearly from the #3-A to #3-C curves. In general, the behavior of cement slurries caused by mixtures #1, #2, and #3 might be classified as Bingham Plastic fluid. Meanwhile, combination #3 has superior rheological properties to mixtures #1 and #2.

3.1.2. THE COUPLED INFLUENCE OF TEMPERATURE AND THE CONCENTRATION OF CHEMICAL ADMIXTURES ON THE PLASTIC VISCOSITY

We conducted a steady-state shear rate sweep on cement slurries at various temperatures. The obtained flow curve was used to determine the plastic viscosity using the Bingham plastic model. Because of the significant uncertainty in the Bingham model's fitting curve, the observed plastic viscosity may not always accurately represent the material and can occasionally be misleading. However, because mechanical models for the deformation behavior of cement paste based on apparent viscosity at each shear rate point are extremely difficult to develop, plastic viscosity was tested and reported in this section. The changes in plastic viscosity (PV) for three concentrations and temperatures are depicted in Figures 13 to 15. The slope of plastic viscosity graphs drops nearly inexorably as the dispersant concentration increases. The decrease in plastic viscosity of cement slurry is due to the dispersant's dispersion feature, which improves the slurry's flowability and inhibits the flocculation of components. By the way, increasing the temperature significantly decreases the viscosity of plastic. Because the plastic viscosity of mixes #2 and #3 is identical, the slope of the graphs is similar at different

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temperatures. In any case, mixture #3 has a lower plastic viscosity and greater flowability than mixtures #1 and #2, owing to the combination's stronger dispersant dispersion feature.

3.1.3. THE COUPLED INFLUENCE OF TEMPERATURE AND CHEMICAL ADMIXTURE CONCENTRATION ON YIELD STRESS

Figures 16-18 illustrate the changes in yield stress for each mixture at three different concentrations and temperatures. At 140°F, increasing the dispersant concentration while decreasing the retarder concentration results in a slight reduction in yield stress. According to Figure 17, yield stress changes caused by dispersant concentration and temperature changes exhibit the same behavior. As a result, yield stress decreases as temperatures rise. Increasing the dispersant concentration in mixture #1 increases yield stress and drop at 170°F. This result is also valid at 160°F and 170°F for mixture #3. The admixture functioning as an accelerator, a previously observed phenomenon, could explain the higher yield stress with increasing admixture concentration. Yield stress changes with temperature are slightly more sensitive in mixture #2 than in mixtures #1 and #3, and yield stress changes with dispersant concentration are slightly less abrupt in mixture #2 than in mixtures #1 and #3; additionally, mixture #2's dispersant and retarder are more effective at higher temperatures. At both 160°F and 170°F, yield stress changes are nearly identical. As a result, the dispersant and retarder in mixture #3 are more desirable at moderate temperatures. At 140°F, the yield stress of mixture #3 acts significantly better than that of mixtures #1 and #2. (Circulation temperature of the desired oil well).

3.1.4. THE COUPLED INFLUENCE OF TEMPERATURE AND CHEMICAL ADMIXTURE CONCENTRATION ON APPARENT VISCOSITY

Figures 19–21 illustrate apparent viscosity changes for three different mixtures and temperatures. The apparent viscosity and plastic viscosity diagrams exhibit a similar trend in that the apparent viscosity decreases as the dispersant concentration and temperature increase. The apparent viscosity vs. dispersant concentration graph shows the three mixtures' negative slope straight-line trend. The concentrations of mixtures #3 and #2 produce the optimal and optimal results, respectively.

3.1.5. THE EFFECT OF TEMPERATURE AND THE CONCENTRATION OF CHEMICAL ADMIXTURES ON THE 10-SEC AND 10-MIN GEL STRENGTH

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Tables 6 to 8 list each mixture's 10-second and 10-minute gel strength concentrations. As indicated in Table 6, as the dispersant concentration increases, the quantity of 10-sec and 10-min gel strength steadily decreases. This is reasonable since increasing the dispersant concentration enhances material dispersion in the cement slurry, hence reducing the cement slurry's flocculation and gelation qualities. As the temperature of the constant concentration increases, the amount of 10-sec gel strength decreases, but the amount of 10-min gel strength gradually increases. The 10-minute gel strength is larger at 160°F and 170°F because of the increased rate of hydration and subsequent stiffening of the slurry. Mixture #2 behaves identically to mixture #1 at the same temperature and concentration.

On the other hand, the quantity of 10-second gel strength in combination #2 is less than the quantity of 10-second gel strength in mixture #1. The difference in 10-sec and 10-min gel strength concentrations in mixture #2 is much greater than in the 10-sec and 10-min gel strength concentrations in mixture #1. The greater the difference between the volumes of cement slurry with a 10-second gel strength and the volume with 10-minute gel strength, the stronger the cement slurry's gelation characteristic. The ideal circumstance is for 10-second and 10-minute gel strength to remain constant. The 10-sec and 10-min gel strengths of mixture #3 are not comparable to those of mixtures #1 and #2 because the 10-min gel strength increases with temperature and dispersant concentration. As seen in Table 8, increasing the dispersant concentration decreases the 10-sec gel strength while increasing the 10-min gel strength. Variations in dispersant concentration had no noticeable effect on changes in 10-minute gel strength, as indicated in Table 8. Between 10 seconds and 10 minutes, the variance in gel strength is substantially smaller in combination #3 than in combinations #1 and #2, showing that mixture #3 is less than mixtures #1 and #2.

3.2. FREE WATER EXPERIMENTS

Figures 22-24 illustrate the amounts of free water diagram for three different dispersant concentrations at ambient pressure and temperature for each mixture. The maximum free water permitted in cement slurries is 3.5 milliliters per 250 milliliters of cement slurry. In Figure 22, free water is reduced by raising the dispersant concentration. However, the amount specified above exceeds the maximum permitted concentration in each of the three concentrations. Free water

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is decreased gradually in figure 23 by increasing the dispersant concentration until the amount specified above equals the critical amount. As a result, it can be determined that the reliance on free water on dispersant concentration is greater in mixture #1 than in mixture #2. Thus, by incorporating FLC (D-167) into both mixtures #1 and #2, the amount of free water would be lowered to zero, resolving the problem. Free water is insignificant in mixture #3, and the issue would be determined at greater dispersant concentrations. As a result, there is no reason to employ FLC. Combining #3 outperforms mixtures #1 and #2 in terms of free water content. In Figure 25, the amount of free water in the three combinations is compared.

3.3. COMPRESSIVE STRENGTH AND THICKENING TIME AS A FUNCTION OF CHEMICAL ADMIXTURE CONCENTRATIONS

Due to the small number of experiments in this section, compressive strength and thickening time tests at 170°F and 140°F are performed solely on mixture #3. The worst-case scenarios are chosen for their rheological qualities and free water content; subsequent testing includes compressive strength and thickening time. The thickening time and compressive strength of mixtures #3 and #3* are shown in Table 9. Using an ADR compression machine, the compressive strength of mixture #3-A is determined to be 4,670 psi after 24 hours. At this point, 0.133 percent BWOC Nano-silica is added to the slurry to determine the compressed strength after 24 hours. Compressive strength has been enhanced to 6,070 psi. This is why nano-silica particles with extremely tiny diameters provide excellent surfaces. On these surfaces, the possibility of performing high-pozzolanic actions has been provided. C-S-H gel is formed when nano-silica particles react with the calcium hydroxide produced during the water-cement hydration procedure. C-S-H gel was previously identified as the primary component responsible for the concrete paste's strength. Compressive strength reduces to 0.267 percent BWOC and 0.4 percent BWOC, respectively, due to Nano-silica concentration. The porosity of concrete #3*-B and #3*-C is increased. Nano-silica acts as an additive at the Nano-scale, resulting in durable concrete construction. If applied more than the required amount, the concrete becomes porous and brittle. The time needed to thicken combination #3-A was 190 minutes before adding Nano-silica but increased to 230 minutes after adding Nano-silica. Nano silica may be regarded as a

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retardant. In any event, combination #3*-A is the optimal choice; it is also analogous to field data. The concrete scheme for combination #3*-A is shown in Figure 26.

3.4. COMPARISON OF LABORATORY AND FIELD DATA

The experimental results obtained from mixes #1, #2, and #3 are compared to field data in this section (desired oil field). The worst-case scenarios for mixtures #1, #2, and #3 are selected. In terms of rheological characteristics and free water, combinations #1 and #2 and mixtures #1-A and #2-A are the poorest. At 140°F, Figure 27 depicts three combinations, including mixture #1-A, mixture #2-A, and the desired oil field. As a result, mixtures #1-A and #2-A exhibit superior rheological qualities to the intended cement slurry, as their outcome diagrams are lower than the desired oil field diagram. Plastic viscosity, apparent viscosity, the yield stress of mixtures #1-A, #2-A, and chosen oil field at 140°F are shown in Table 10. Both combinations outperform the intended oil field regarding perceived viscosity and yield stress. There is a significant difference in the content of yield stress, in particular. Only the plastic viscosity of combination #2-A is more than that of the required oil field. The best plastic viscosity is found in mixture #1-A, while the best yield stress is found in mixture #2-A. In other words, the dextrose-citric acid (CA) mixture has a stronger effect on yield stress than on plastic viscosity. The combination of calcium lignosulfonate (CLS) and boric acid (BA) in mixture #2 has a greater effect on plastic viscosity than the yield stress. At 140°F, Figure 28 plots shear stress vs. shear rate for mixtures #3-A, #3*-A, and desired oil field. In the worst-case scenario, observes mixture #3 outperforms field data regarding rheological qualities. The effect of Nano-silica was investigated at combination #3*-A. The shear stress vs. shear rate diagram changes from curves to linear conditions, approximating a Newtonian fluid situation. The plastic viscosity, apparent viscosity, yield stress, compressive strength, thickening time of mixture #3-A, #3*-A, and desired oil field data are all compared in Table 11. Observe that combination #3-A outperforms the intended oil field in all circumstances. The plastic viscosity, apparent viscosity, and yield stress decrease significantly when Nano-silica is added to mixture #3*-A. Plastic viscosity is reduced by 64%, and yield stress is reduced by 93%, which is rather significant. Additionally, the compressive strength of combination #3*-A doubles with the desired oil field. Finally, the optimal blend was determined to be #3*-A. Each experimental test conducted on this blend was successful.

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4. CONCLUSIONS

This research aims to enhance the rheological properties of oil well cement slurries by developing new cement slurries with a new material generation. Additionally, the amount of free water, the compressive strength, and the time required for thickening are examined. Temperature, water-cement ratio, kind of admixture, and concentration all significantly affect the characteristics of cement slurries. The current research has been successful in establishing various critical points, including the following:

1. The shear stress vs. shear rate diagram is crucial for developing the cement slurry's fluid model and rheological parameters. Temperature and dispersant concentration are the most important elements affecting the rheological characteristics of cement slurry. As temperature and concentration increase, the slope of the shear stress vs. shear rate plot drops, and the data pattern changes from curvature to linear behavior.
2. The plastic viscosity decreases relative to the initial value as the temperature and dispersant concentration increase. Meanwhile, the temperature has a considerably greater effect on plastic viscosity than dispersant concentration. Plastic viscosity is optimal when D-1 is used as dispersion and R-1 is used as a retarder. The dispersion and retarder compositions of Dex and CA had the least effect on the plastic viscosity of cement slurry, respectively.
3. As temperature and dispersant concentrations increase, yield stress decreases rather smoothly. Meanwhile, temperature impacts result in far more stress than dispersant concentration. The best yield stress is obtained when D-1 is used as dispersion and R-1 is used as a retarder. When employed as dispersion and retarder, CLS and BA had the slightest impact on the yield stress of cement slurry.
4. Because apparent viscosity behaves nearly identically to plastic viscosity, decreasing temperature and dispersant concentration decrease apparent viscosity. As a result, D-1 and R-1 have the highest apparent viscosity compared to other admixtures.
5. Concentration has the greatest effect on the quantity of 10-second and 10-minute gel strength, such that the amount of both decreases as dispersant concentration increases. Because temperature has a different impact on 10-sec and 10-min gel strength, the laboratory specifies the effect of temperature on the unique mixture's 10-sec and 10-min gel

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strength. All that remains is to increase the difference between the 10-sec and 10-min gel strengths and increase the slurry gelation as the temperature increases. In comparison to other admixtures, D-1 and R-1 have the least gelation.

6. Free water decreases as the concentration of dispersion increases, and the concentration of retarder decreases. CLS and BA have the lowest free water content, whereas D-1 and R-1 have the most.
7. In the laboratory, compressive strength has a reciprocal relationship with dispersant concentration, except dispersant can be added up to a particular concentration. Compressive strength is increased by adding a new component such as Nano-silica for the reasons discussed.
8. Because the quantity of thickening time in the cement slurry is dependent on the retarder utilized, thickening time increases as the retarder concentration in the cement slurry increases.
9. The present technical data for chemical admixtures must be confirmed for use in oil well cementing; admixtures that are efficient at raised temperatures in conventional cementing work may become ineffective at elevated temperatures in oil well cementing.
10. Finally, it was found that mixture #3*-A was the optimal blend. Each experiment with this mixture was a success. This mixture can be employed in the desired oil field with 4,200-6,900 feet (formation of the Gachsaran and Asmari reservoirs) and pressure and temperature range of 4,100-4,800psi and 140-170°F, respectively. The result will be better than the existing version because this mixture enhances the rheological properties of cement slurry. After all, the plastic viscosity, apparent viscosity, and yield stress diagrams of mixture #3*-A are lower than the desired oil field and the other mixtures in this study, leading to a decrease in cement slurry viscosity. Moreover, it has the highest compressive strength among all of these mixtures. After 24 hours, the compressive strength increased to around 6,070 psi using Nano-silica, which is excellent for setting circumstances. Thus, the results of these tests can be used to resolve and minimize operational problems such as a sharp increase in slurry viscosity at the wellhead and bottom hole, an increase in pumping pressure, and the risk of fracture in weak formations, and pipeline depreciation.

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Conflict of Interest

There are no conflicts of interest.

Data Availability Statement

The datasets generated and supporting the findings of this article are obtainable from the corresponding author upon reasonable request. The authors attest that all data for this study are included in the paper.

Funding Data

No funds have been allocated to this project.

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Table 1. API class G cement slurry chemical and physical properties (Shahriar, 2011)

Chemical Component (%)		Physical Properties	
Silica (SiO ₂)	21.6	Fineness 45 μ m sieve	92.4% passing
Alumina (Al ₂ O ₃)	3.3	Blaine (Spec. Surf.)	385 m ² /kg
Iron Oxide (Fe ₂ O ₃)	4.9	Thickening Time (Schedule 5)	110 min
Calcium Oxide, Total (TCaO)	64.2	Compressive strength at 8 hours @ 38°C	2.1 MPa
Magnesium Oxide (MgO)	1.1	Compressive strength at 8 hours @ 60°C	10.3 MPa
Sulphur Trioxide (SO ₃)	2.2		
Loss on Ignition	0.60		
Insoluble Residue	0.30		
Equivalent Alkali (as Na ₂ O)	0.41		
C ₃ A	<1		
C ₃ S	62		
C ₂ S	15		
C ₄ AF+2 C ₃ A	16		

Table 2. Composition of mixture #1

Mixture #1	Cement (gr)	Water (gr)	Dispersant** (%BWOC)	Retarder** (%BWOC)	FLC (%BWOC)
A	750	320	1.066	0.67	0.4
B	750	320	1.2	0.533	0.4
C	750	320	1.33	0.4	0.4

**Dispersant+Retarder=1.73 %BWOC and constant

Table 3. Composition of mixture #2

Mixture #2	Cement (gr)	Water (gr)	Dispersant** (%BWOC)	Retarder** (%BWOC)	FLC (%BWOC)
A	750	320	1.066	0.67	0.4
B	750	320	1.2	0.533	0.4
C	750	320	1.33	0.4	0.4

**Dispersant+Retarder=1.73 %BWOC and constant

Table 4. Composition of mixture #3

Mixture #3	Cement (gr)	Water (gr)	Dispersant** (%BWOC)	Retarder** (%BWOC)	FLC (%BWOC)
A	750	325	0.53	0.3	14.5
B	750	325	0.6	0.23	14.5
C	750	325	0.67	0.166	14.5

**Dispersant+Retarder=0.83 %BWOC and constant

Table 5. Composition of mixture #3*

Mixture #3	Cement (gr)	Water (gr)	Dispersant** (%BWOC)	Retarder** (%BWOC)	NaCl (%BWOW)	Nano Silica (%BWOC)
A	750	325	0.53	0.3	14.5	0.133
B	750	325	0.53	0.3	14.5	0.266
C	750	325	0.53	0.3	14.5	0.4

**Dispersant+Retarder=0.83 %BWOC and constant

¹Corresponding author.



Figure 1. Schematic of a cement slurry mixer



Figure 2. Schematic of a cement consistometer



Figure 3. Schematic of a cement consistometer

¹Corresponding author.

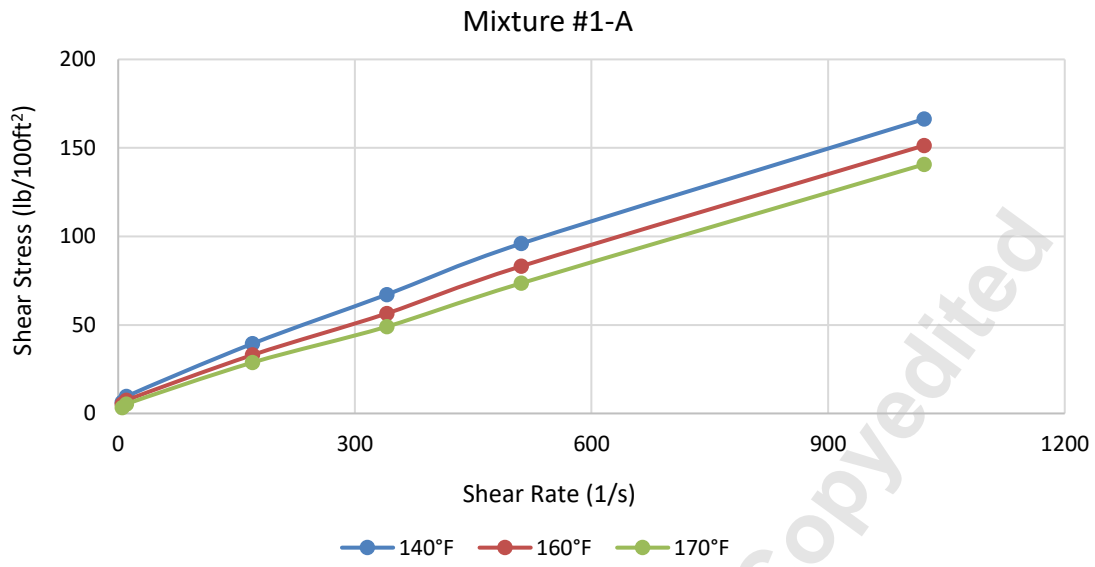


Figure 4. Temperature effect on mixture #1-A's shear stress vs. shear rate curve

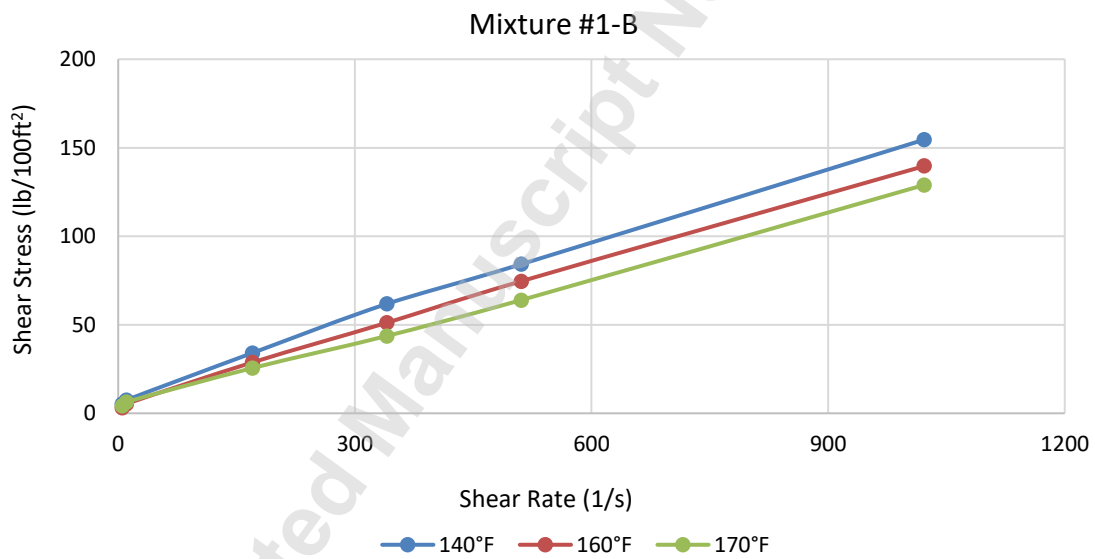


Figure 5. Temperature effect on mixture #1-B's shear stress vs. shear rate curve

¹Corresponding author.

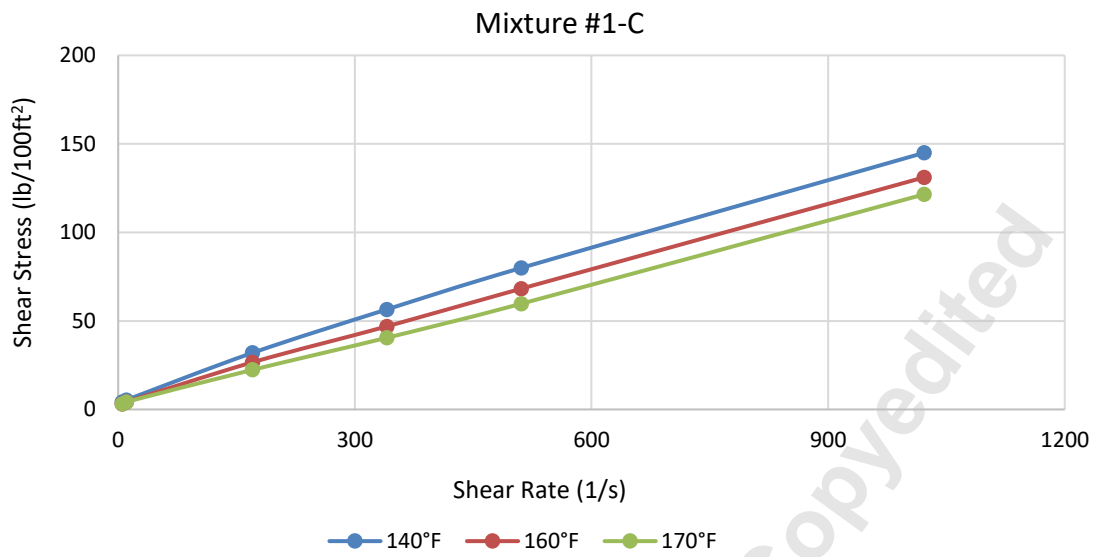


Figure 6. Temperature effect on mixture #1-C's shear stress vs. shear rate curve

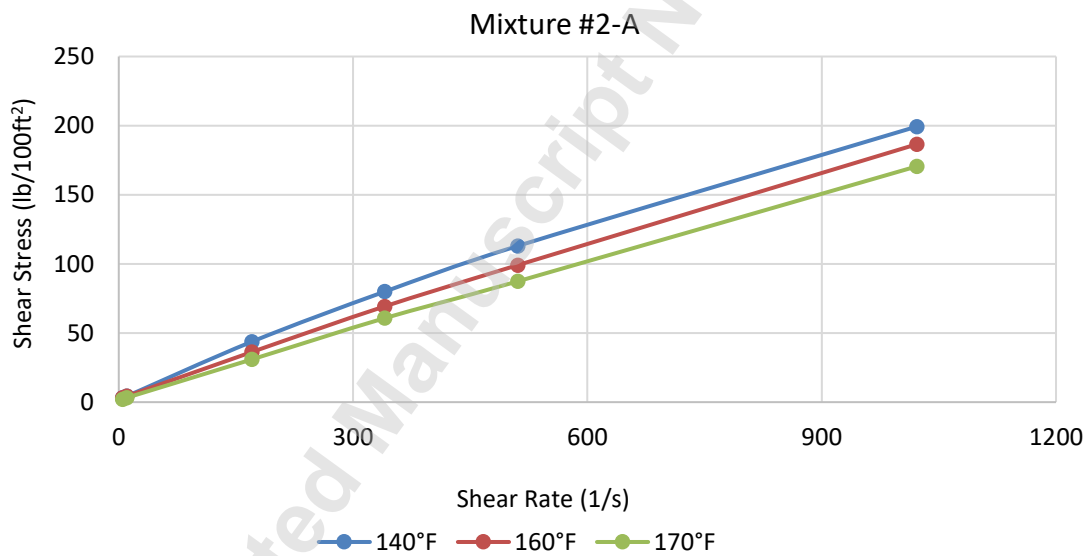


Figure 7. Temperature effect on mixture #2-A's shear stress vs. shear rate curve

¹Corresponding author.

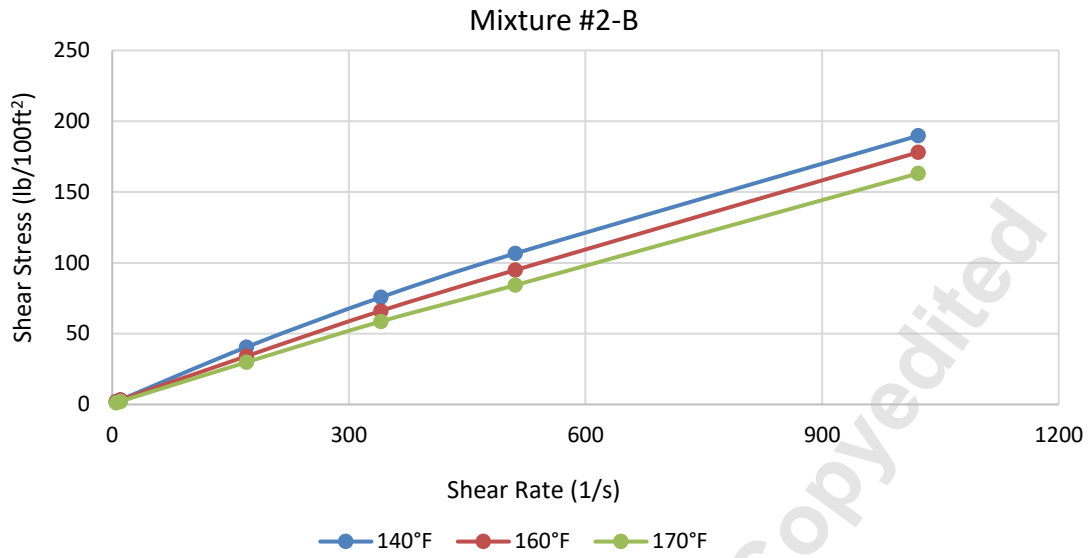


Figure 8. Temperature effect on mixture #2-B's shear stress vs. shear rate curve

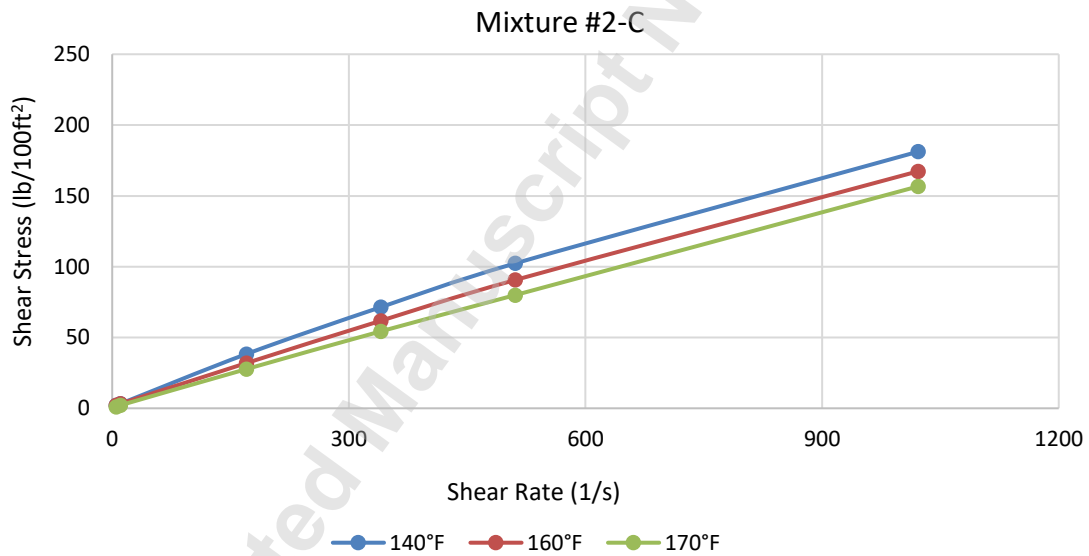


Figure 9. Temperature effect on mixture #2-C's shear stress vs. shear rate curve

¹Corresponding author.

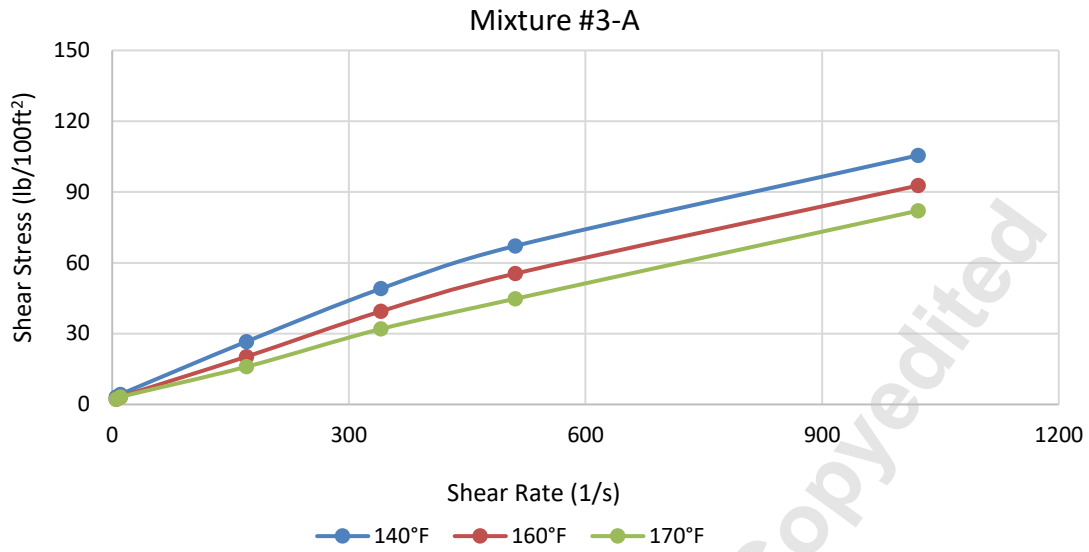


Figure 10. Temperature effect on mixture #3-A's shear stress vs. shear rate curve

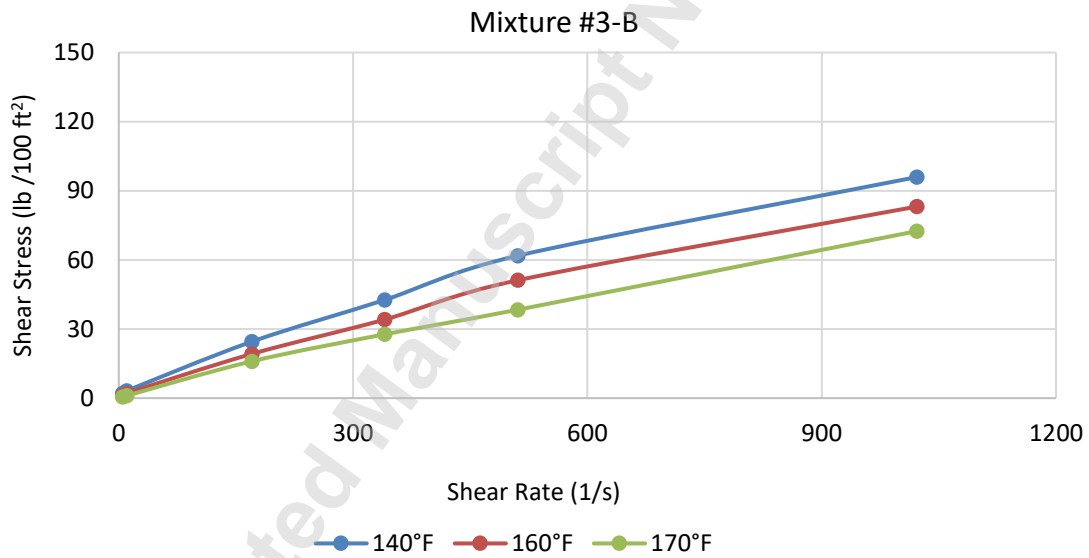


Figure 11. Temperature effect on mixture #3-B's shear stress vs. shear rate curve

¹Corresponding author.

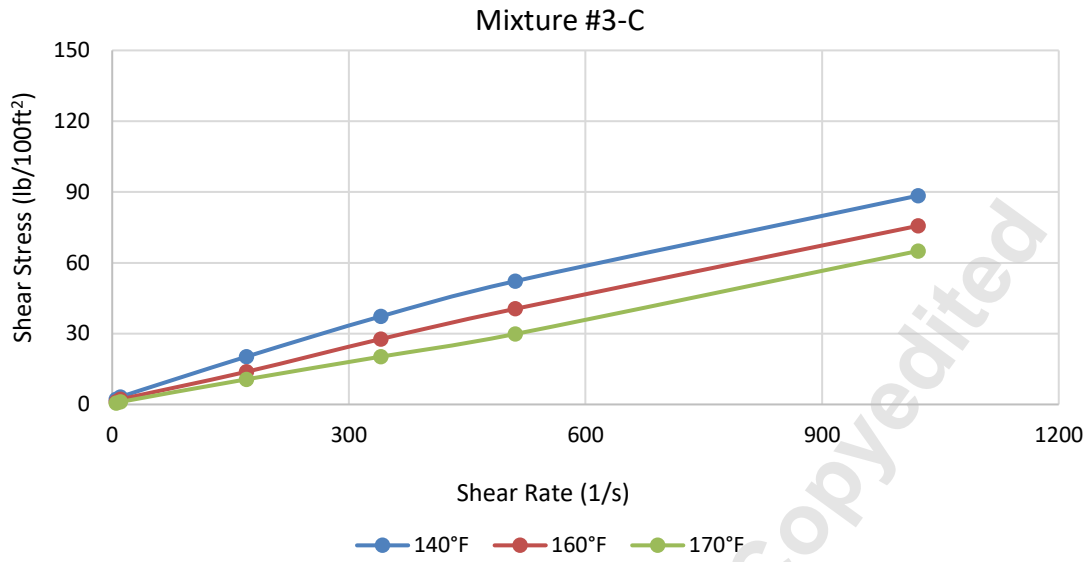


Figure 12. Temperature effect on mixture #3-C's shear stress vs. shear rate curve

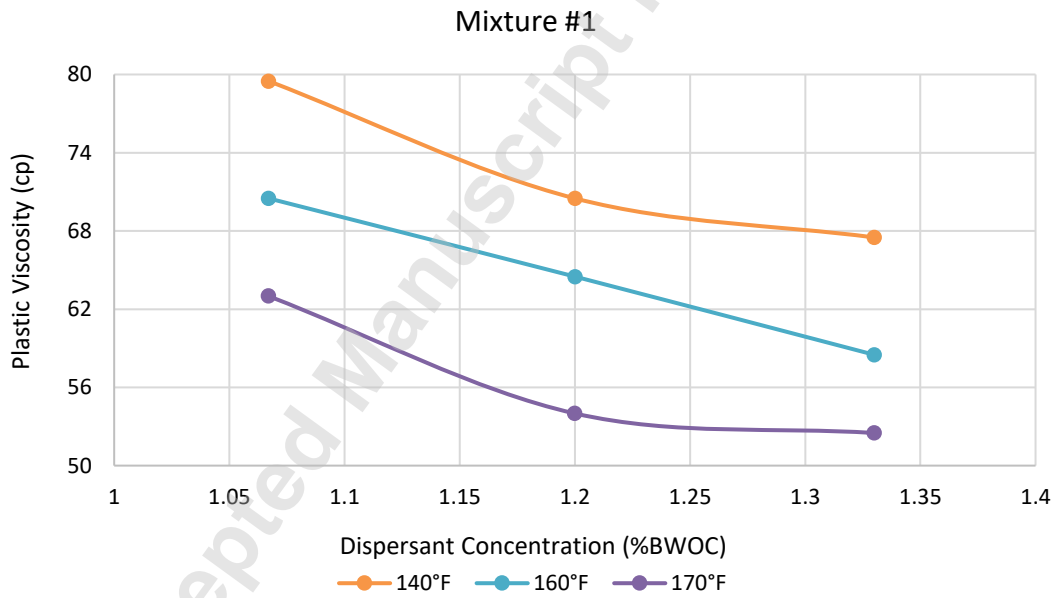


Figure 13. Plastic viscosity of mixture #1 at various temperatures and with varying admixture proportions

¹Corresponding author.

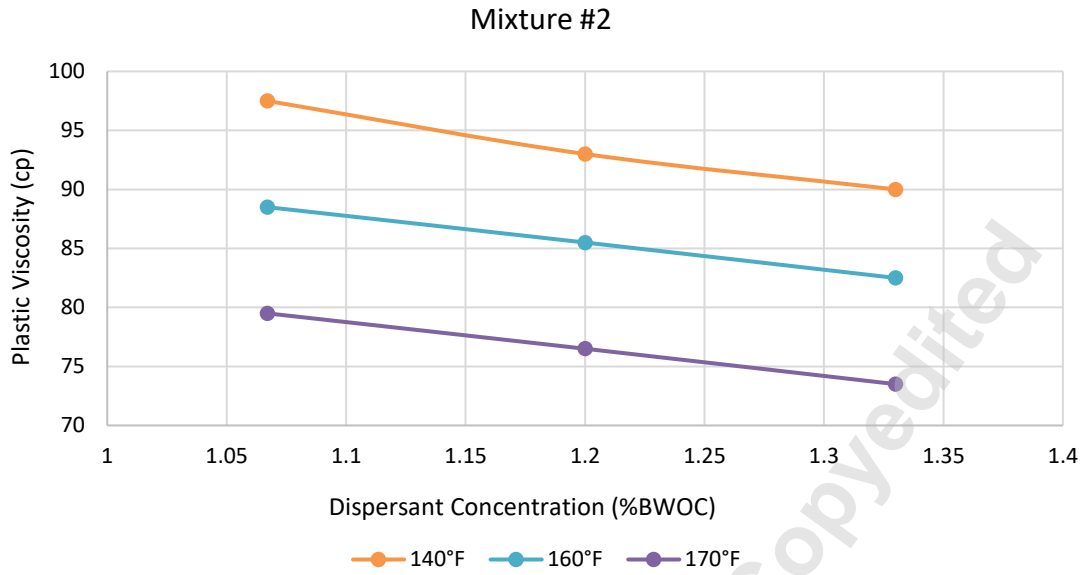


Figure 14 Plastic viscosity of mixture #2 at various temperatures and with varying admixture proportions

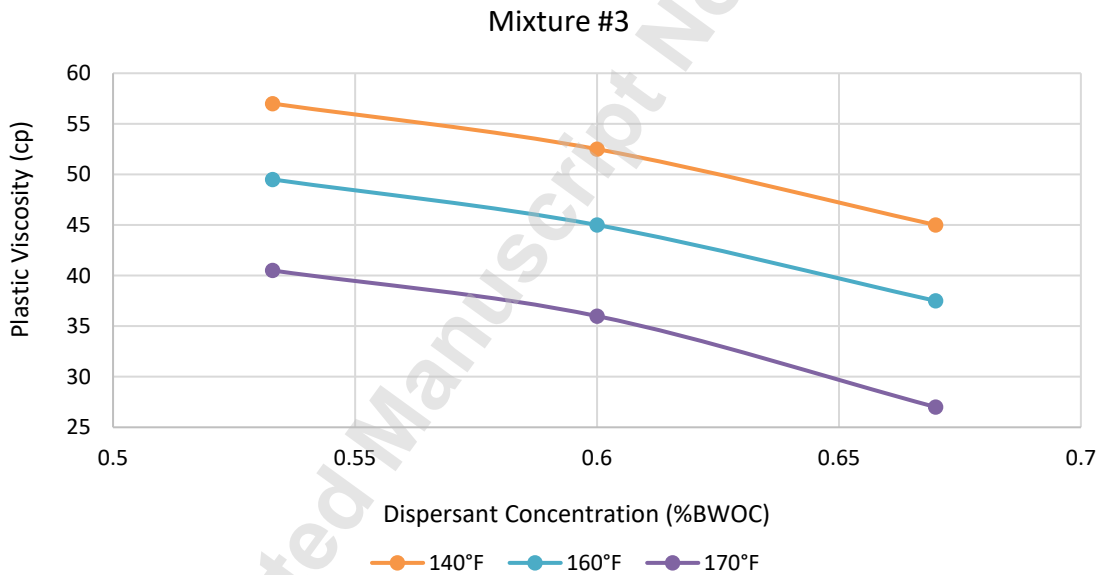


Figure 15 Plastic viscosity of mixture #3 at various temperatures and with varying admixture proportions

¹Corresponding author.

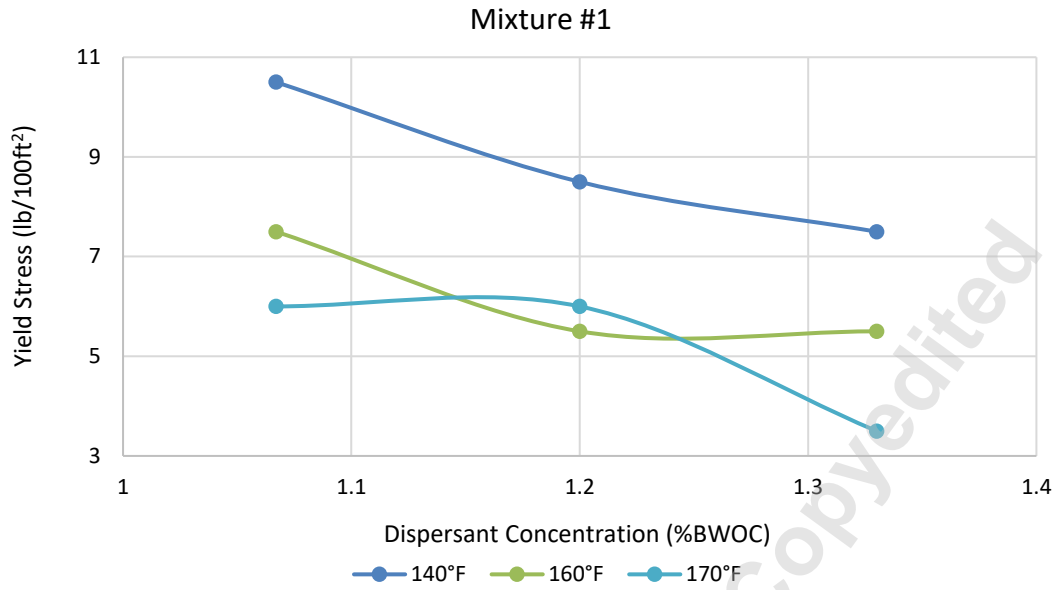


Figure 16. Yield stress of mixture #1 at different temperatures and admixture concentrations

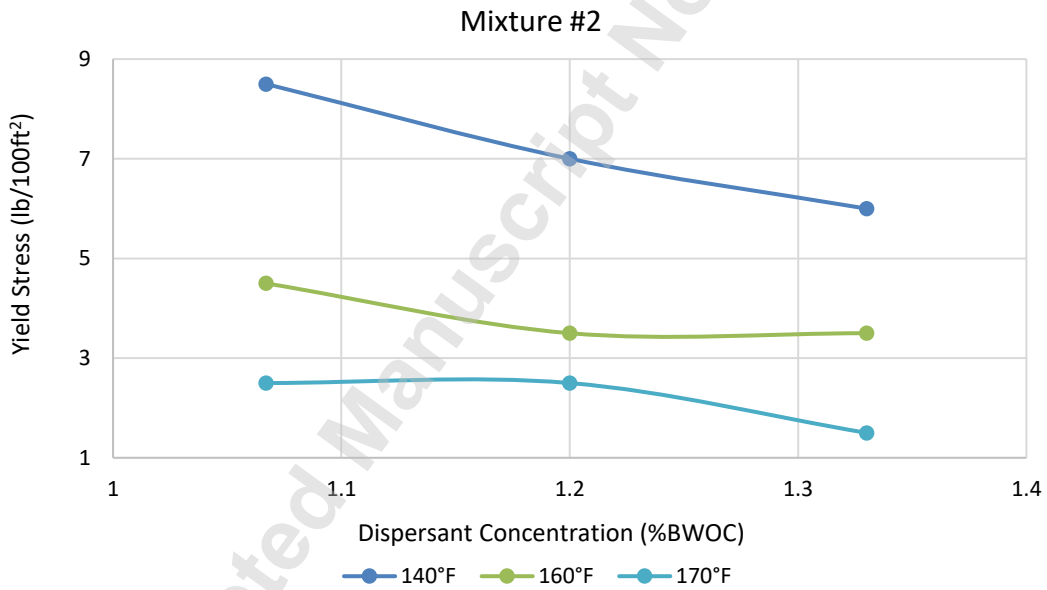


Figure 17. Yield stress of mixture #2 at different temperatures and admixture concentrations

¹Corresponding author.

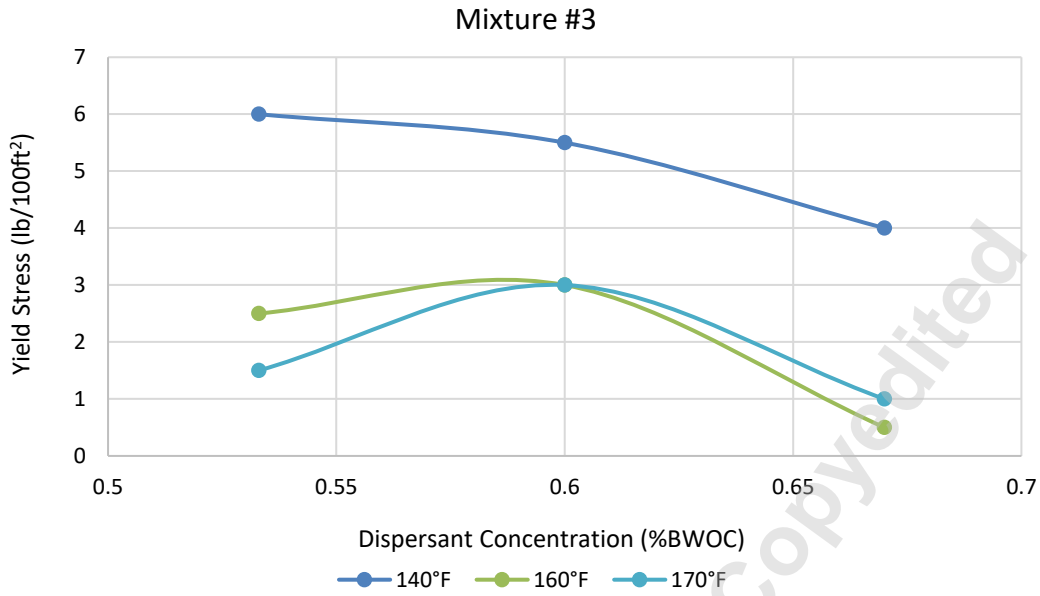


Figure 18. Yield stress of mixture #3 at different temperatures and admixture concentrations

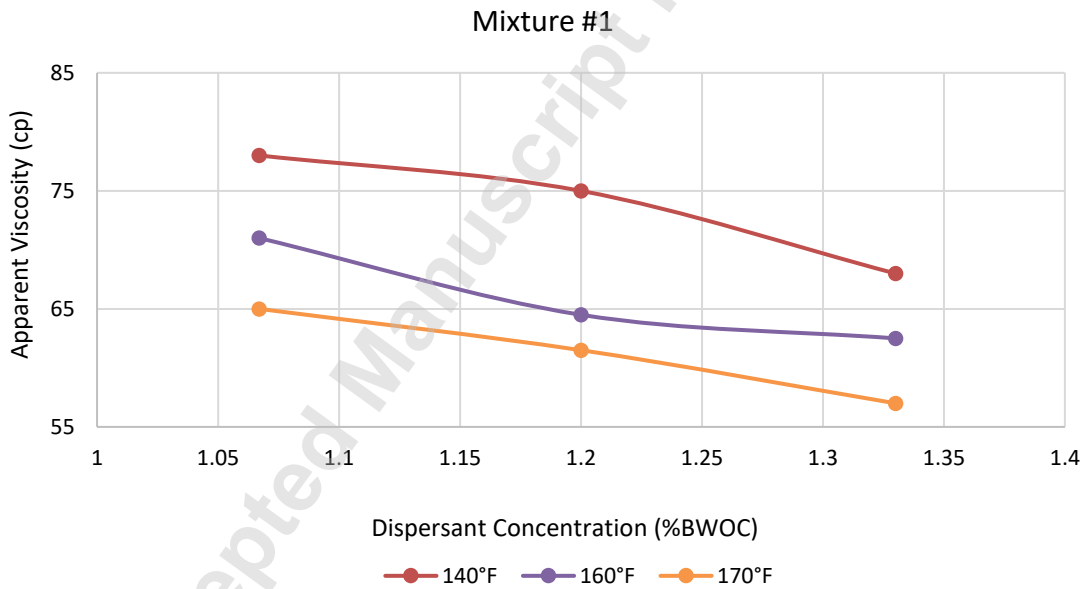


Figure 19. Apparent viscosity of mixture #1 at various temperatures and admixture concentrations

¹Corresponding author.

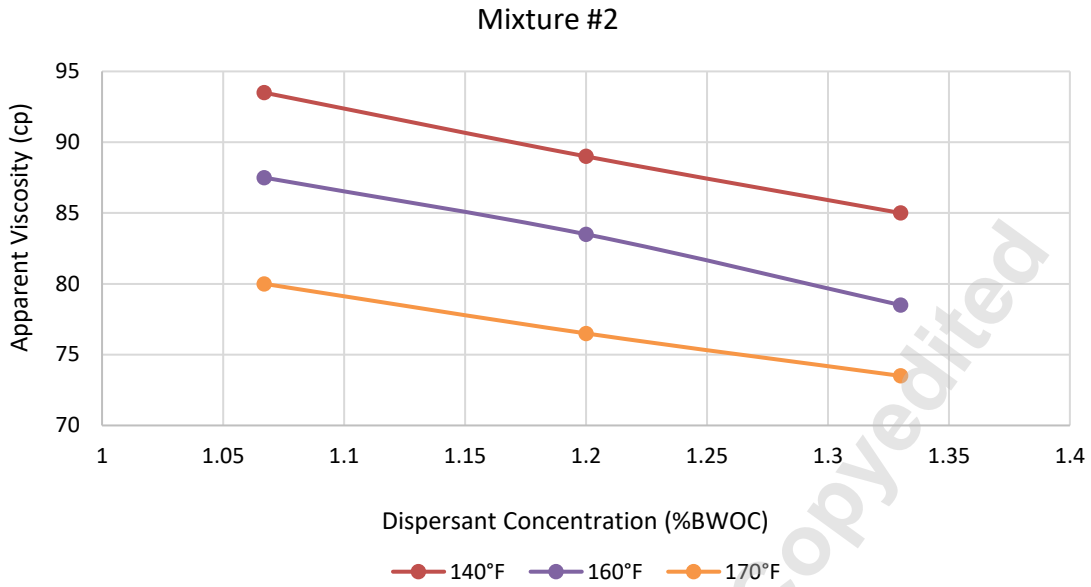


Figure 20. Apparent viscosity of mixture #2 at various temperatures and admixture concentrations

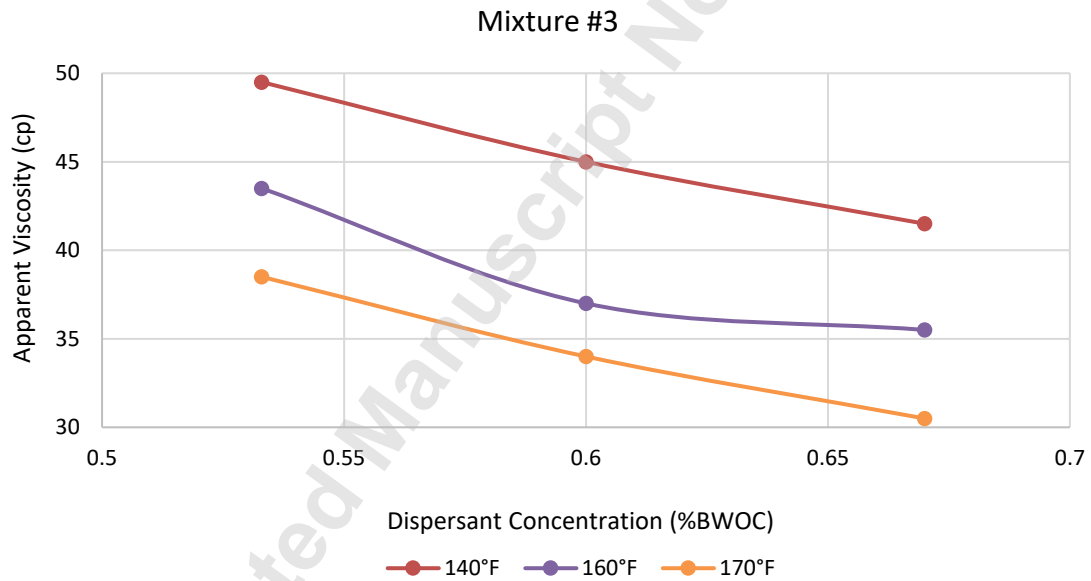


Figure 21. Apparent viscosity of mixture #3 at various temperatures and admixture concentrations

¹Corresponding author.

Table 6. 10-seconds and 10-minutes Gel strength of mixture #1 at different temperatures and admixture concentrations

Mixture	Dosages of Dispersant (%BWOC)	140°F		160°F		170°F	
		10-sec Gel Strength (lb/100ft ²)	10-min Gel Strength (lb/100ft ²)	10-sec Gel Strength (lb/100ft ²)	10-min Gel Strength (lb/100ft ²)	10-sec Gel Strength (lb/100ft ²)	10-min Gel Strength (lb/100ft ²)
Mixture #1	1.066	6.396	10.66	5.33	11.726	3.198	11.726
	1.2	5.33	8.528	4.264	9.594	3.198	10.66
	1.33	4.264	6.396	3.198	6.396	2.132	7.462

Table 7. 10-seconds and 10-minutes Gel strength of mixture #2 at different temperatures and admixture concentrations

Mixture	Dosages of Dispersant (%BWOC)	140°F		160°F		170°F	
		10-sec Gel Strength (lb/100ft ²)	10-min Gel Strength (lb/100ft ²)	10-sec Gel Strength (lb/100ft ²)	10-min Gel Strength (lb/100ft ²)	10-sec Gel Strength (lb/100ft ²)	10-min Gel Strength (lb/100ft ²)
Mixture #2	1.066	3.198	10.66	4.264	12.792	5.33	14.924
	1.2	2.132	8.528	3.198	10.66	4.264	11.726
	1.33	2.132	5.33	2.132	7.462	3.198	10.66

Table 8. 10-seconds and 10-minutes Gel strength of mixture #3 at different temperatures and admixture concentrations

Mixture	Dosages of Dispersant (%BWOC)	140°F		160°F		170°F	
		10-sec Gel Strength (lb/100ft ²)	10-min Gel Strength (lb/100ft ²)	10-sec Gel Strength (lb/100ft ²)	10-min Gel Strength (lb/100ft ²)	10-sec Gel Strength (lb/100ft ²)	10-min Gel Strength (lb/100ft ²)
Mixture #3	0.533	1.066	3.198	2.132	3.198	2.132	4.264
	0.6	1.066	4.264	2.132	4.264	2.132	6.396
	0.66	0.533	4.264	1.066	5.33	3.198	7.462

¹Corresponding author.

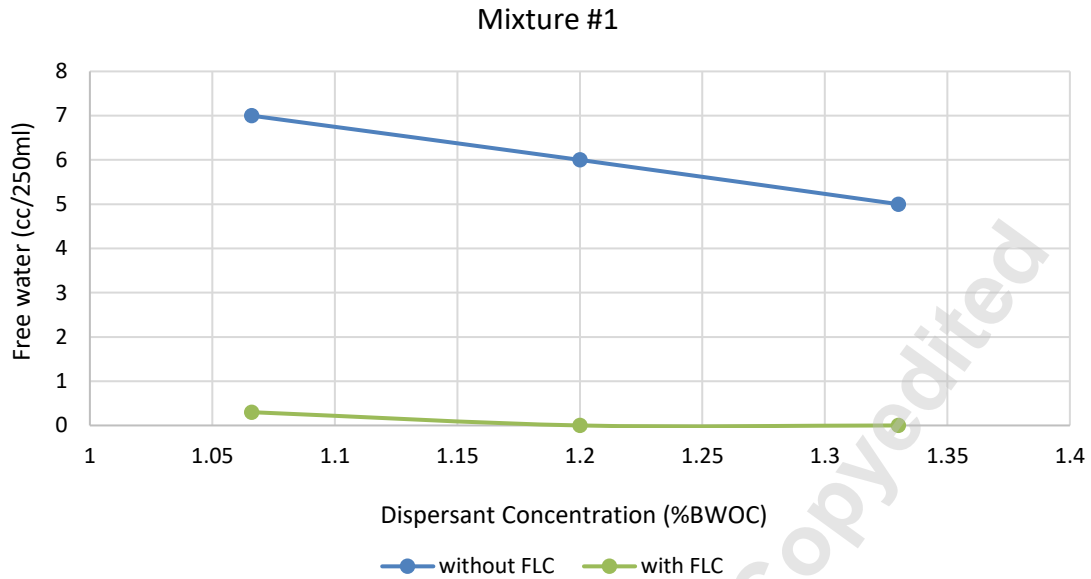


Figure 22. The free water content of mixture #1 with and without FLC at various admixture concentrations

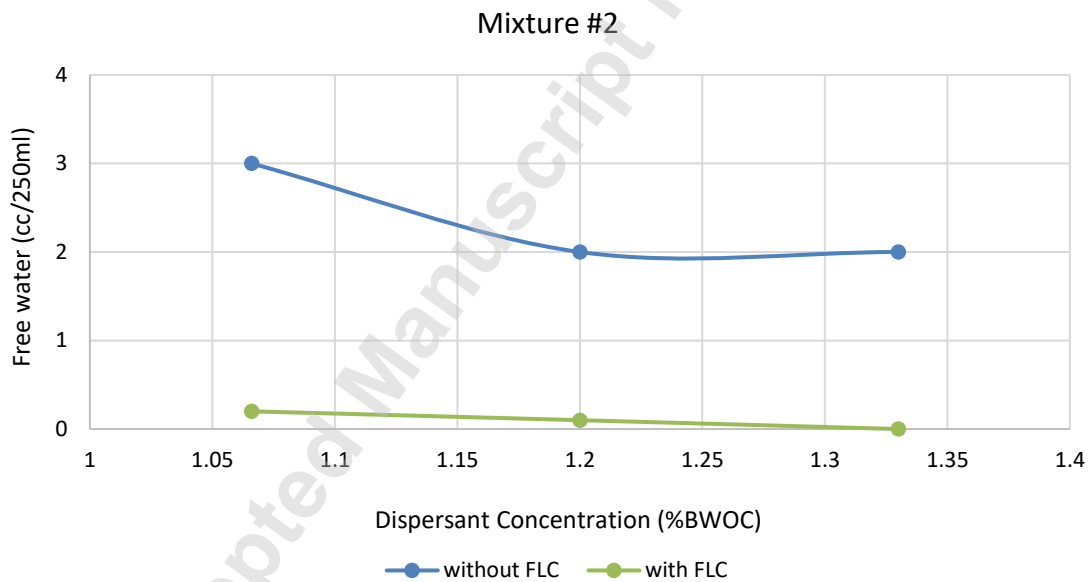


Figure 23. The free water content of mixture #2 with and without FLC at various admixture concentrations

¹Corresponding author.

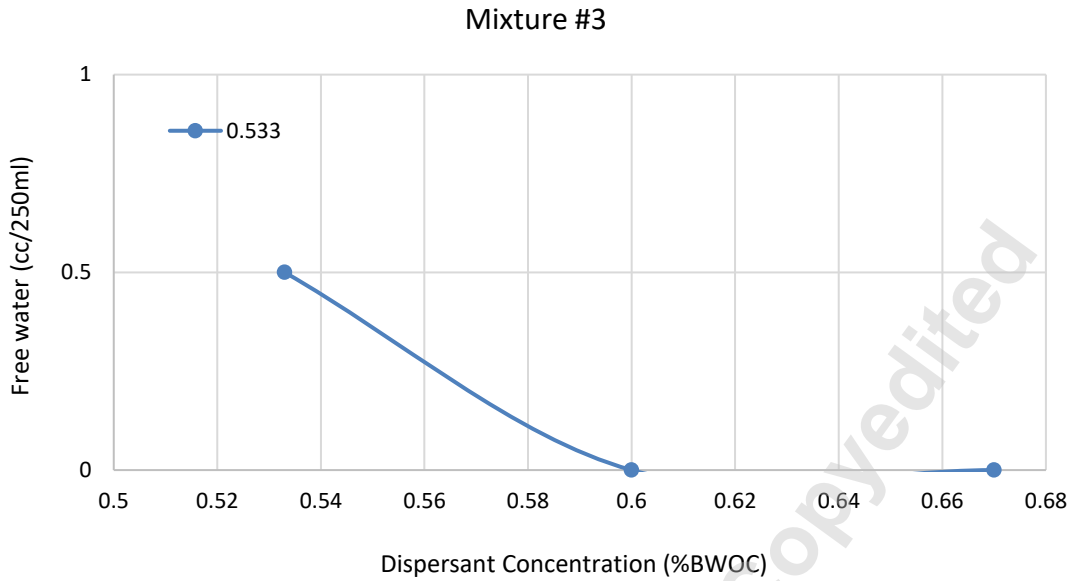


Figure 24. The free water content of mixture #3 with and without FLC at various admixture concentrations

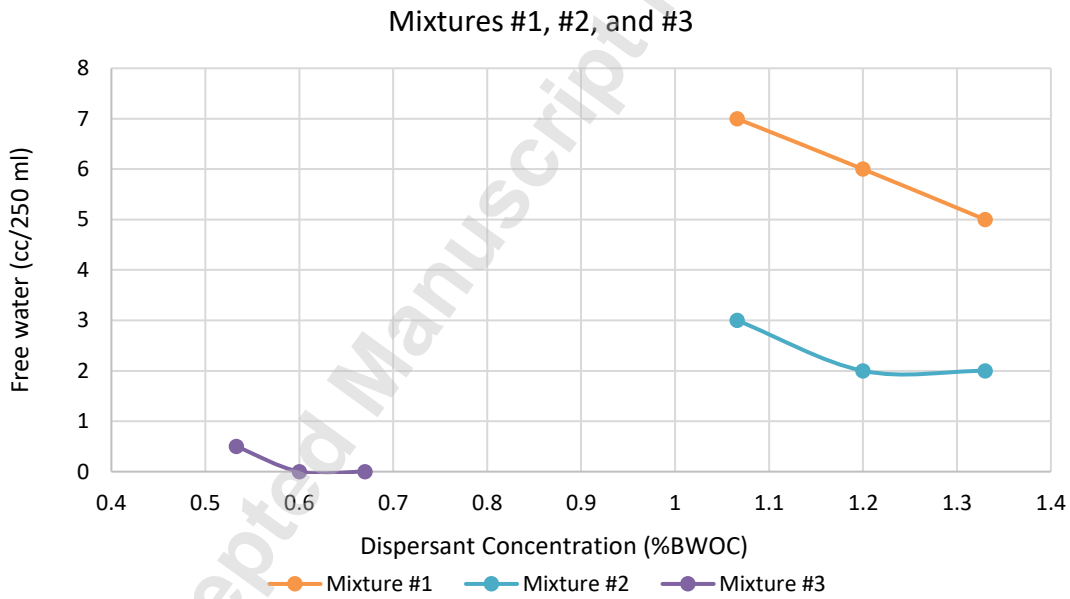


Figure 25. Comparing the free water content of mixes #1, #2 (without FLC), and #3 at various admixture amounts

¹Corresponding author.

Table 9. Compressive strength and thickening time of mixes #3 and #3* at various admixture concentrations

Mixture	170°F	140°F
	Compressive Strength 24 hr (psi)	Thickening Time (min)
Mixture #3-A	4,670	190
Mixture #3*-A	6,070	230
Mixture #3*-B	4,530	-
Mixture #3*-C	3,120	-



Figure 26. A schematic of concrete of mixture #3*-A

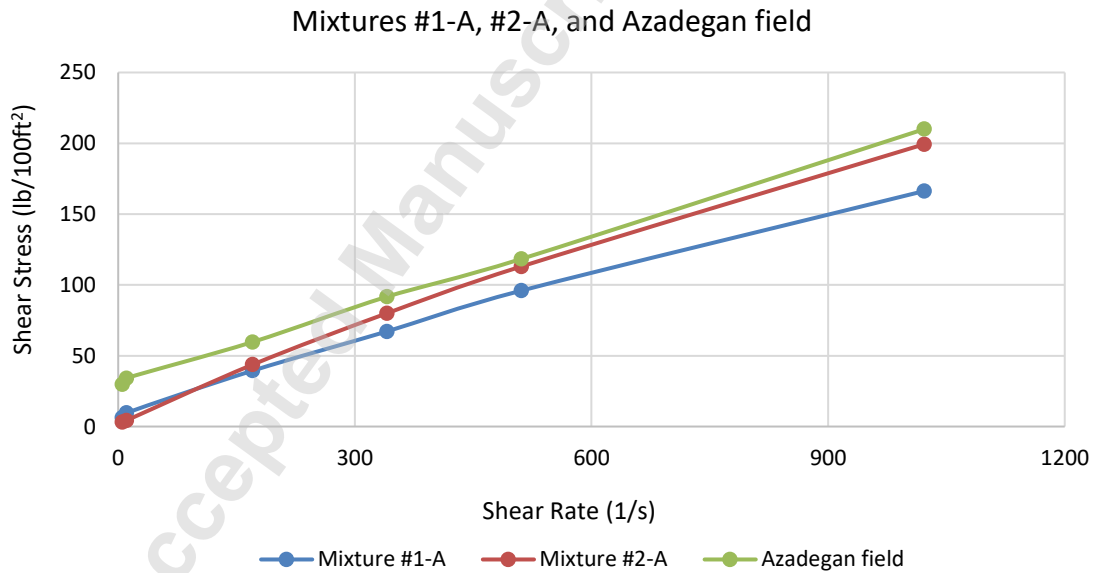


Figure 27. Comparing mixtures #1-A and #2-A's shear stress vs. shear rate curves with desired oil field data at 140°F

¹Corresponding author.

Table 10. Comparing the plastic viscosity, yield stress, and apparent viscosity of mixtures #1-A and #2-A with data from the desired oil field

Mixture	140°F		
	Plastic Viscosity (cp)	Yield Stress (lb/100ft ²)	Apparent Viscosity (cp)
Mixture #1-A	79.5	10.5	78
Mixture #2-A	97.5	8.5	93.5
Desired oil field	82.5	28.5	98.5

Mixtures #3-A, #3*-A, and Azadegan field

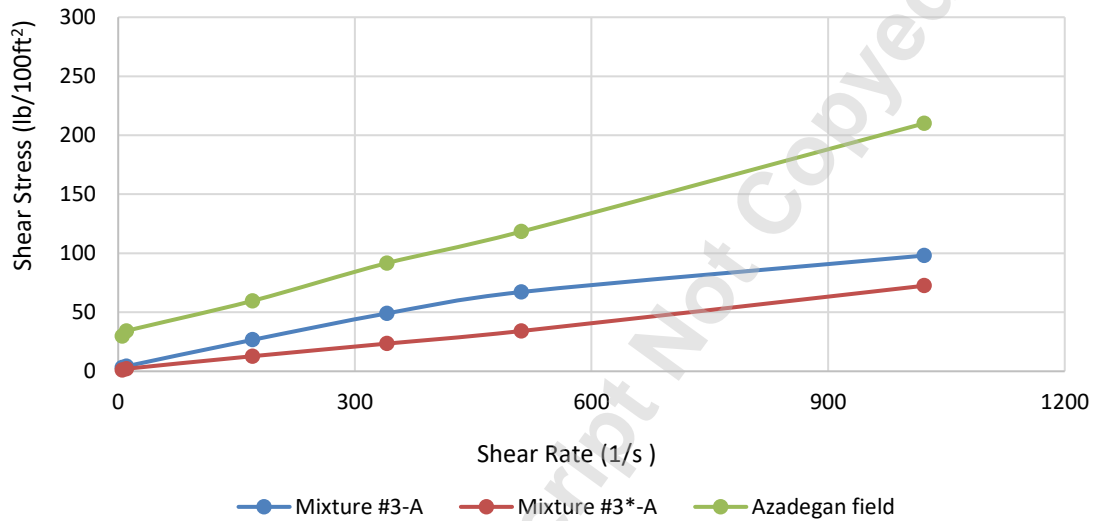


Figure 28. Comparing mixtures #3-A and #3*-A's shear stress vs. shear rate curves with desired oil field data

Table 11. Comparing the plastic viscosity, yield stress, apparent viscosity, compressive strength, and thickening time of mixes #3-A and #3*-A with desired oil field data

Mixture	140 °F				
	Plastic Viscosity (cp)	Yield Stress (lb/100ft ²)	Apparent Viscosity (cp)	Compressive Strength (psi)	Thickening Time (min)
Mixture #3-A	57	6	49.5	4,670	190
Mixture #3*-A	30	2	34	6,070	230
Desired oil field	82.5	28.5	98.5	3,110	237

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